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BAUXITIC AND OTHER DURICRUSTS IN SURINAME: A REVIEW[1]

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ABSTRACT

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The bauxite deposits and ferritic duricrusts of Suriname are arranged in four groups, based on their geology and a number of other parameters. In an appendix five examples are described in sufficient detail to illustrate the essential mutual differences and similarities.

The four groups of deposits are related to the geomorphological history of Suriname, from which a genetic history for the bauxite and other duricrusts evolves. It also becomes clear that, although saprolitic weathering occurred four or five times during Tertiary and Quaternary history, in Suriname only the Late Eocene-Oligocene weathering period was of sufficient intensity to produce accumulation zones and duricrusts that could withstand later erosion, denudation and planation activities. Several of these old duricrusts are now being mined for bauxite.

INTRODUCTION

The bauxite deposits of Suriname have been mined since the beginning of this century and for some time they have been – and still are – a major source of aluminous raw materials for the western world. Several studies on the geology of a few of these deposits have been published but some are outdated by now or are incomplete; this is notably the case with the often cited work by VAN KERSEN (1955).

With the first symposium of IGCP Project 129 (Laterites and lateritization processes) to take place by the end of 1979, it seems appropriate to review and summarize the present understanding of the geology of bauxite and other duricrusts in Suriname.

As will become apparent later in the paper, the published studies and investigations on Suriname's various duricrusts are unevenly distributed over the known occurrences. This is due to the remoteness of certain occurrences and the lack of economic interest in the occurrences of low alumina content; it is certainly also the result of company policies vis-a-vis scientific publications on the geology of their concessions.

GEOLOGICAL SETTING

The knowledge of the geology of Suriname has reached a mature stage with the publication in 1978 of a new geological map (scale 1:500000); it is understood that the accompanying explanation is ready for printing.

Suriname is situated on the northern slope of the Guiana Shield, stretching from the central divide area to the Atlantic Ocean, a distance of about 400 km. Northward from the divide (the Suriname-Brazil international boundary) a series of geological-geomorphological belts or zones may be distinguished (see also figure 1):

(1) The mountains of the central divide area, 900-1250 m high, with savannas in between.
(2) The upper reaches of the northerly draining main rivers with parallel mountain and hill ranges, with elevations up to 1000 m.
(3) The middle courses of the same rivers, flowing in a flat area 50 to 100 m in elevation with isolated mountains and hills.
(4) The Coastal Savanna Belt, 20-40 m high, partly underlain by Precambrian gneisses, granites and schists and partly by Tertiary sediments.
(5) The Coastal Plain, 1-20 m in elevation, composed of Tertiary and Quaternary unconsolidated sediments.

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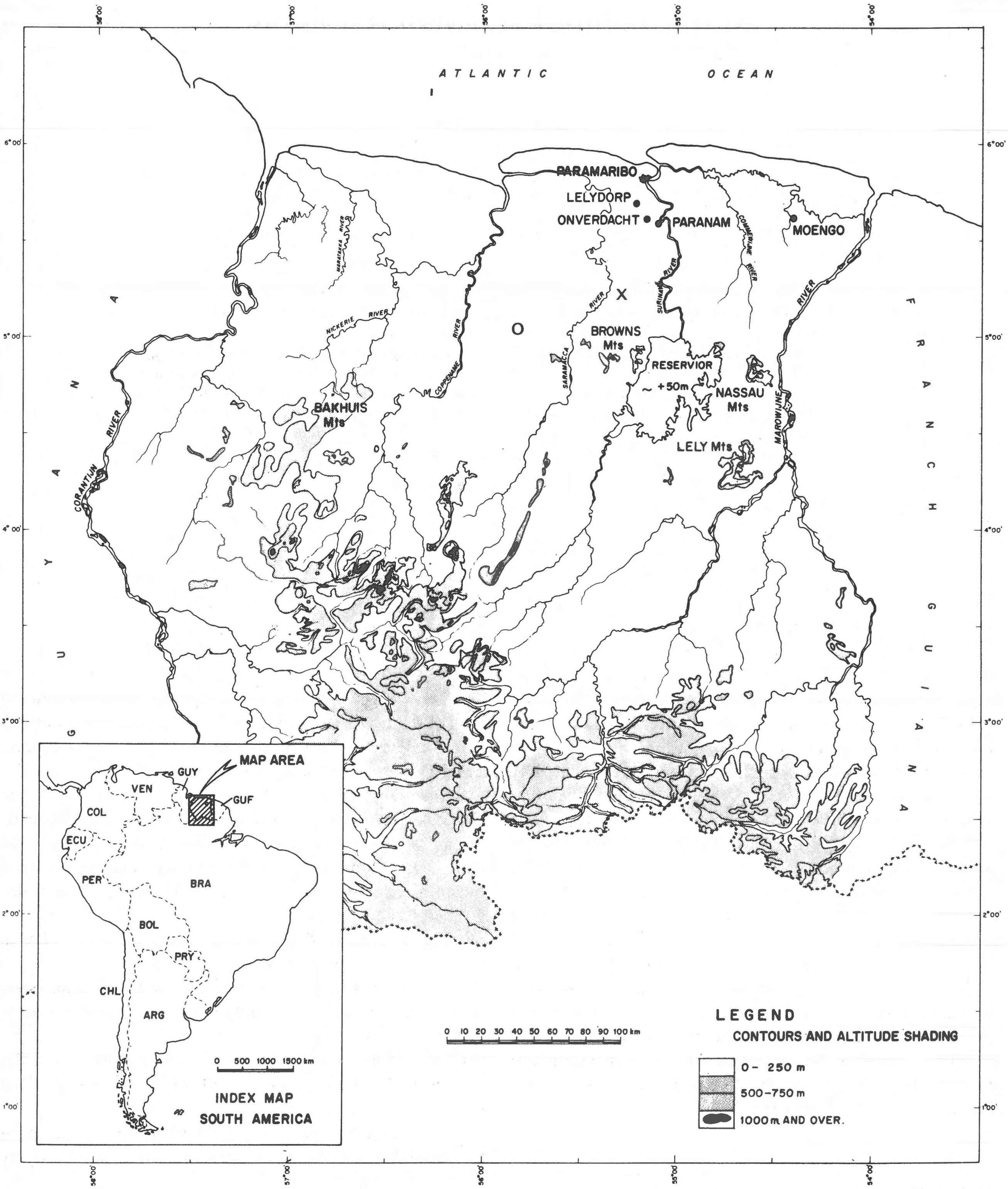
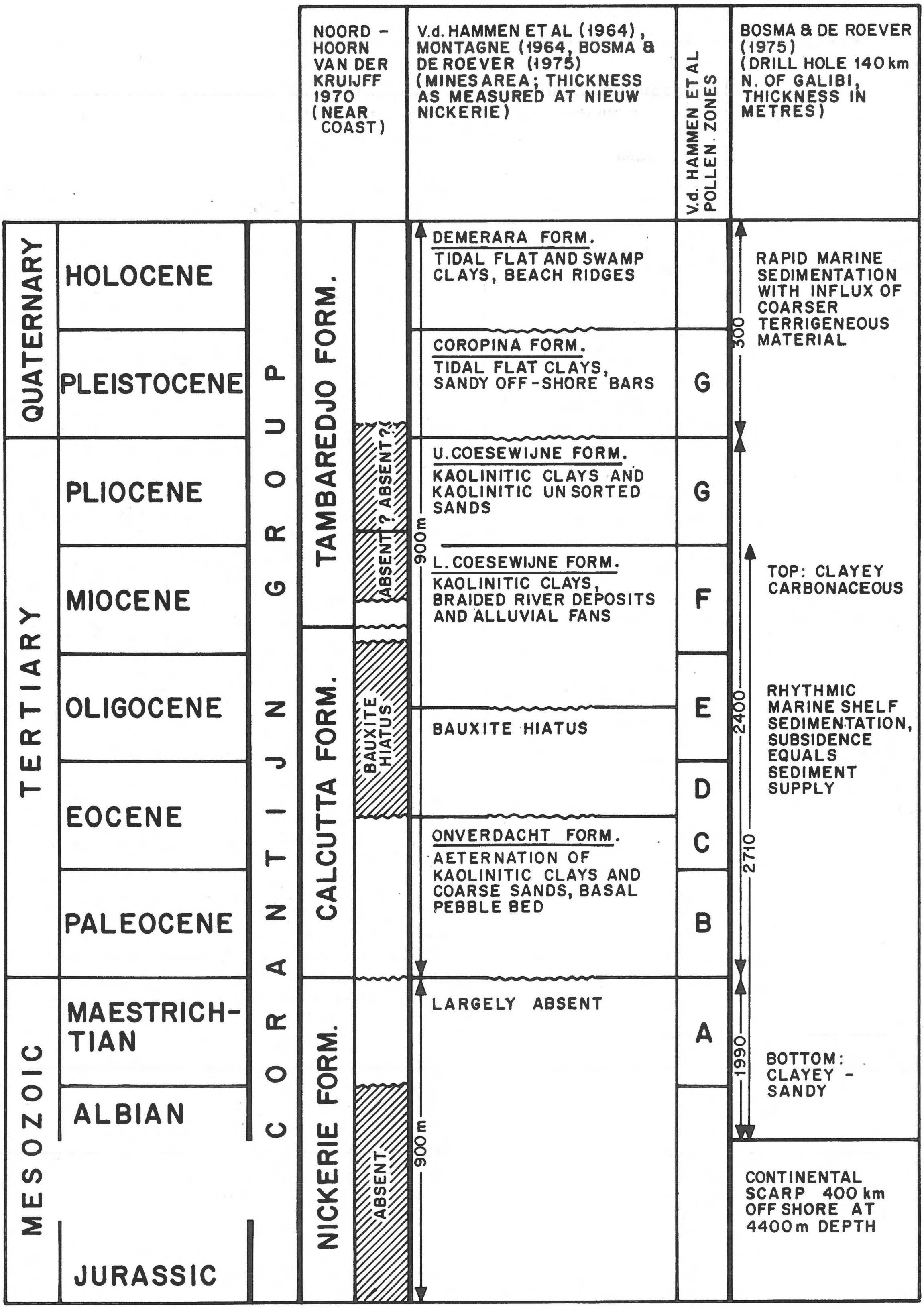


Fig. 1
Map of Suriname showing drainage pattern and contour lines of 250, 500, 750 and 1000 m elevation. x = Kwakoegron; o = Tibiti River rapids.

Table I
Condensed stratigraphic-lithologie table for Suriname (largely after Bosma & De Roever, 1975).

		CORANTIJN GROUP 0-80 Ma	Unconsolidated sediments transgressing Precambrian basement; formation of bauxitic and other duricrusts; see Table II.
		APATOE DOLERITE 230± 10 Ma	N-S striking dikes of pigeonite dolerite
NICKERIE METAMORPHIC EPISODE		KABALEBO AUGEN-GNEISS 1200±100 Ma	blastomylonitic augengneiss, low-grade metamorphic, in zones parallel to the Bakhuis horst
		AVANAVERO DOLERITE 1659± 27 Ma	mainly NE striking dikes and also sills of hypersthene-bearing pigeonite dolerite and gabbro
		RORAIMA FORMATION 1655± 18 Ma	well bedded, often reddish quartz-sandstones and conglomerates with some ash flows; up to 700 m thick.
TRANS-AMAZONIAN OROGENIC CYCLE	MAGMATISM	GRANITE SUITE 1874± 40 Ma	biotite granite with microcline megacrysts; tonalite and muscovite granite; pyroxene-bearing granite; leucogranite and granophyric granite spatially associated with rhyolite, dacite and andesite (Dalbana rhyolite).
		DE GOEJE GABBRO 1818±165 Ma	gabbros, ultramafitites in small (max. 15 km in size) differentiated bodies; older than granite suite.
	LOW-GRADE METAMORPHISM	MAROWIJNE GROUP 2045±115 Ma	greenschist facies rocks with plutono-metamorhphism in amphibolite facies around granites and tonalites; two environments: Armina (flysh-like sequence) and Rosebel/Ston (molasse-like sequence) Formation.
			Paramaka Formation (Matapi spilite) with eugeosynclinal basis and intermediate volcanics associated with siliceous, carbonaceous and chemical metasediments (including gondite, itabirite, calc-silicate rocks)
	HIGH-GRADE METAMORPHISM	COEROENI GROUP 2000±100 Ma Kanuku Complex FALAWATRA GROUP 2000-2400 Ma or older	biotite-, sillimanite-, and hornblende gneisses, amphibolites, amphibolite and granulite facies metamorphism polymetamorphic charnockitic granulites, enderbites; granulite facies metamorphism surrounded by sillimanite-, pyroxene- and biotite gneisses and amphibolites, correlated with the Coeroeni Group rocks



			NOORD - HOORN VAN DER KRUIJFF 1970 (NEAR COAST)		V.d. HAMMEN ET AL (1964), MONTAGNE (1964, BOSMA & DE ROEVER (1975) (MINES AREA; THICKNESS AS MEASURED AT NIEUW NICKERIE)	V.d. HAMMEN ET AL POLLEN. ZONES	BOSMA & DE ROEVER (1975) (DRILL HOLE 140 km N. OF GALIBI, THICKNESS IN METRES)
QUATERNARY	HOLOCENE	CORANTIJN GROUP	TAMBAREDJO FORM.		900 m **DEMERARA FORM.** TIDAL FLAT AND SWAMP CLAYS, BEACH RIDGES		300 RAPID MARINE SEDIMENTATION WITH INFLUX OF COARSER TERRIGENEOUS MATERIAL
	PLEISTOCENE				**COROPINA FORM.** TIDAL FLAT CLAYS, SANDY OFF-SHORE BARS	G	
TERTIARY	PLIOCENE			ABSENT ? ABSENT?	**U.COESEWIJNE FORM.** KAOLINITIC CLAYS AND KAOLINITIC UNSORTED SANDS	G	2710 2400
	MIOCENE			ABSENT?	**L.COESEWIJNE FORM.** KAOLINITIC CLAYS, BRAIDED RIVER DEPOSITS AND ALLUVIAL FANS	F	TOP: CLAYEY CARBONACEOUS
	OLIGOCENE		CALCUTTA FORM.	BAUXITE HIATUS	BAUXITE HIATUS	E	RHYTHMIC MARINE SHELF SEDIMENTATION, SUBSIDENCE EQUALS SEDIMENT SUPPLY
	EOCENE				**ONVERDACHT FORM.** AETERNATION OF KAOLINITIC CLAYS AND COARSE SANDS, BASAL PEBBLE BED	D C	
	PALEOCENE					B	
MESOZOIC	MAESTRICHTIAN		NICKERIE FORM.		900 m LARGELY ABSENT	A	1990 BOTTOM: CLAYEY - SANDY
	ALBIAN			ABSENT			CONTINENTAL SCARP 400 km OFF SHORE AT 4400 m DEPTH
	JURASSIC						

Table II
Stratigraphy of the Coastal Plain of Suriname.

(6) The off-shore continuation of the Tertiary and Quaternary sediments; further off-shore with Jurassic and Cretaceous sediments as the oldest rocks, with a total of almost 5000 m of sediments overlying the Precambrian basement.

Tables I and II give a summary of the stratigraphy and lithology of the Precambrian basement and the mainly Cainozoic unconsolidated sediments of the Coastal Plain respectively; these provide sufficient detail to serve as a basis for studying the weathering products of the various rocks.

Humid tropical weathering, including lateritization and bauxitization, comprises several surface processes, but is essentially a re-equilibration of the mineral phases to the surface environment of 1 bar pressure, 25-35 °C temperature in the tropical regions, and unlimited abundances of H_2O, CO_2 and acids produced by decaying flora and fauna. The resulting saprolite weathering profile shows a characteristic vertical succession of separate horizons (see figure 2). The end products are mainly clays of kaolinitic composition, but under certain conditions a near-surface accumulation horizon is formed. This horizon is enriched in one or more of the oxides of iron, aluminium, titanium and manganese, and it is often developed as a hard layer –or it hardens on exposure– which is the frequently conspicuous duricrust.

This duricrust may constitute economically important iron, bauxite and manganese deposits. It is also the duricrust that prevents quick erosion of the generally soft weathering products and thereby provides interesting clues to the geomorphological history of the region during the last 80 million years.

GEOMORPHOLOGY

On the Guiana Shield KING (1964), MCCONNELL (1968), BERRANGÉ (1977) and others have recognized a series of planation surfaces as elements in a cyclic process of erosion and landscape development. There is now a general agreement on five planation episodes. The levels at which these are developed, however, vary considerably with distance from the ocean (VERHOFSTAD, 1969). From youngest to oldest, the following planation surfaces are distinguished:
(V) *Pleistocene to Recent:* valley floors and river flats along present day rivers and creeks.
(IV) *Late Tertiary II or Pliocene:* the wide, flat but intensely dissected and slightly concave plains between the northerly trending hilly ridges with the major drainage channels in the lowest part (e.g. Suriname, Saramacca, Coppename rivers).
(III) *Late Tertiary I or Oligocene-Early Miocene:* this surface is not well seen in Suriname, contrary to its wide-spread occurrence in Guyana. The hilly areas around the Bakhuis Mountains and some of the hills in the concave Tertiary II surface might belong to this stage. Certainly, the wide, flat valley floors in between the buried bauxite deposits of Onverdacht and Lelydorp belong to this planation surface.

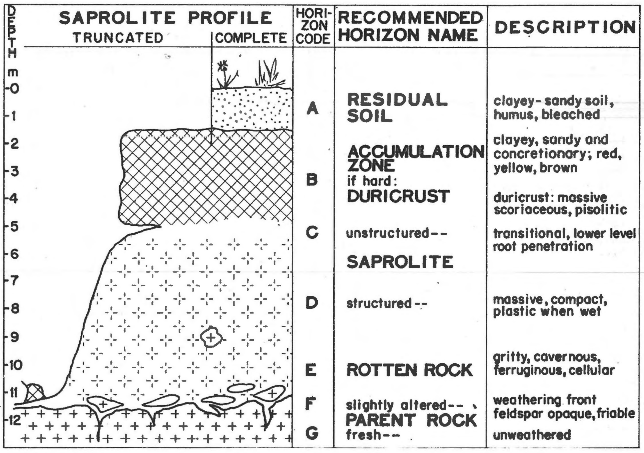


Fig. 2
The standard tropical-weathering profile with its vertical succession of horizons and the lithologies as found on granatic, gneissic or mica-schist parent rock (modified after Millot, 1964 and Lelong, 1969).

(II) *Early Tertiary or Palaeocene-Eocene:* remnants of this surface are conspicuous in the flat-topped and duricrust-capped mountains and hills that are present in the central belt of Suriname, in between the major drainage channels; these are the Nassau and Lely Mountains, Brownsberg and Bakhuis Mountains. This surface is known all over South America and has been named the Sul-Americano surface by King. The correlate sediments from this period are those on which the bauxites are developed in the Onverdacht-Lelydorp area and in the Moengo area.
(I) *Gondwana or Jurassic-Cretaceous:* another continent-wide planation surface which seems to be present as a rather level envelope around the highest mountains of the central divide area of the Guiana Shield. It could include in Suriname the mountain tops of over approx. 1000 m elevation, including the Table Mountain composed of Roraima sandstone.

Figure 3 gives two N-S sections through Eastern Suriname (a + b) and one West-East section (c) in the morphological belt with the middle courses of the main drainage channels. Roman numerals, as used above to indicate the five planation surfaces, mark the surface to which certain features may belong.

CLIMATE

In the Coastal Plain of Suriname, and in several parts of Guyana, it has been possible to study climatic variation by using the pollen spectra found in the unconsolidated Tertiary and Quaternary sediments. VAN DER HAMMEN (1963), VAN DER HAMMEN & WIJMSTRA (1964), WIJMSTRA (1971) and NOORTHOORN VAN DE KRUIJFF (1970) provided most of the information which was succinctly summarized by KROOK

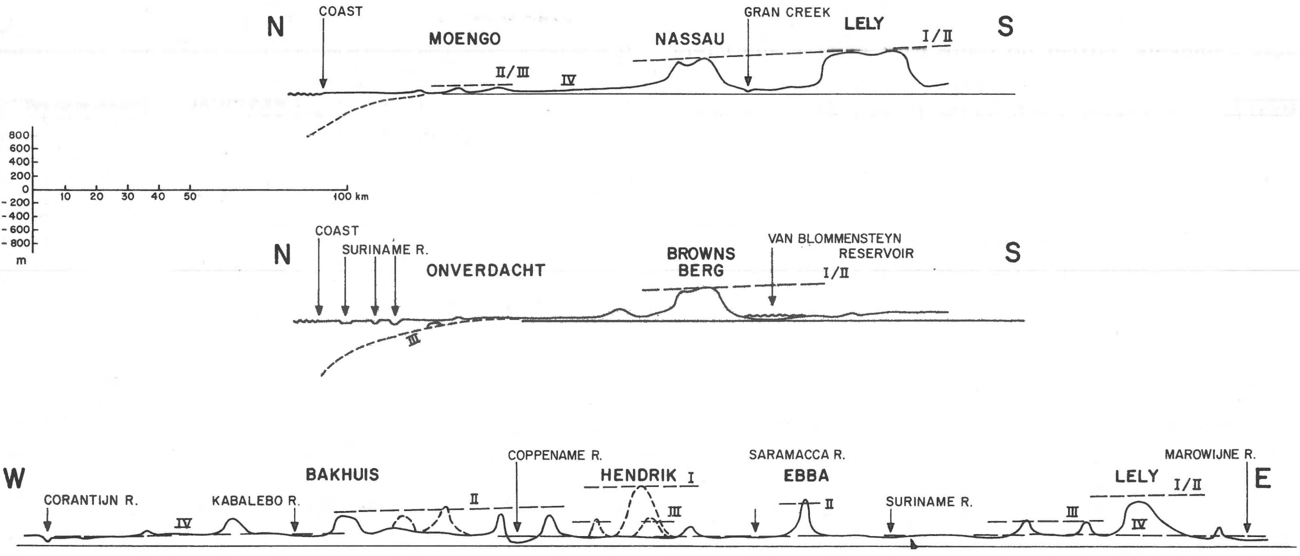
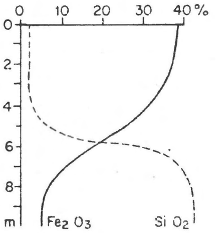
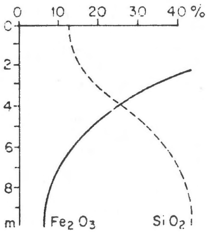
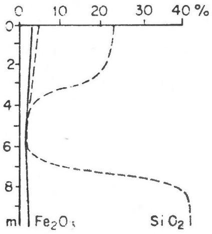
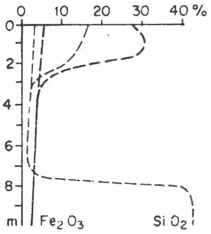


Fig. 3
Three sections through bauxite-capped mountains and their relation to the various planation surfaces.

Table III
Relation of stratigraphy, sea-level movements and climate in the coastal area of Suriname (after Krook, 1979).

Age	Stratigraphy Guiana Basin	pollen zones	sea-level movements	climate	remarks
Holocene	Upper clays	G-2	transgression	mainly humid	
Pleistocene		G-2	transgression and regressions	transgr.: mainly humid regr.: partly rel. dry	
Pliocene	Upper Sands	G-1	mainly regressive	rel. dry during regression	
Late Miocene	no deposits		large regression	rel. dry;	no deposits in coastal plain
Middle Miocene	Intermediate clays	F	transgressive	very humid	
Early Miocene		E-2	large regression	rel. dry	denudation
		E-1	transgression		
Oligocene?	A-sands	no pollen	transgression	no date	
Late Eocene	no deposits		regression	rel. dry	bauxite formation
Middle Eocene	Alternating	D	transgression?	mainly humid	
		C-2	regression		
Early Eocene	Sands	C-1	transgression		
	and				
	clays	B-2	regression		
Palaeocene		B-1	transgression		
			large regression		denudation
Cretaceous	Lower consolidated Sands and clays	A	mainly regressive		

Table IV
Summary of the characteristics of the four types of ferrallitic duricrusts distinguished in Suriname.

Type Parameter	A	B	C	D
APPEARANCE	250-600 m high flat-topped hills, 150-180 km from coast	50-80 m high flat divide areas, 80-90 km from coast	5-80 m high flat-topped hills, 30-40 km from coast	buried flat-topped hills below 0-30 m cover, 20-30 km from coast
PARENT ROCK	charnockites, leucogabbros, gneisses, amphibolites, greenschists of Falawatra and Marowijne Groups, > 1900 Ma	schists and granites of Marowijne Group and Granite Suite, >1900 Ma	unconsolidated sediments of Corantijn Group, 70-50 Ma, and rocks of Marowijne Group and Granite Suite	unconsolidated sediments of Corantijn Group, 70-50 Ma (Palaeocene and Eocene)
DURICRUST ROCK NAMES	ferrite, bauxitic ferrite, ferritic bauxite, bauxite	ferrite, laterite	bauxite, ferritic bauxite	bauxite, ferritic bauxite
MINERALS	hematite (aluminous) goethite gibbsite (boehmite)	hematite (aluminous) goethite kaolinite	gibbsite (boehmite) hematite	gibbsite (boehmite) hematite metahaloysite
TEXTURES	relict textures and joints in top part; medium - fine-grained, massive, granular; colloform, banded, pisolithic, spongy; late Fe_2O_3 neoformations; disseminated crystals, joint fillings, layers of late gibbsite neoformations	insufficiently studied; massive, nodular cellular with banded, colloform late Fe_2O_3 neoformation	relict textures and casts of plant roots and burrows in certain beds; top part fine- medium-grained granular, also breccia-like and columnar lower part mostly earthy with nodules, cellular textures and hard granular beds	relict textures and casts of plant roots and burrows; top part often iron rich, breccia-like and columnar, or iron poor with resilicification veins and dikes with metahaloysite; central part nodular and concretionary gibbsite in clayey gibbsite matrix; lower part often cellular, chambered with gibbsite septa and gibbsite or clay chamber fillings
UNDERLYING CLAY	contact sharp or gradational; relict textures not observed	contact gradational as far as observed	contact sharp to gradational, most likely as result of primary stratified parent rock; relict textures frequently present; gibbsitic beds (5-75 cm thick) intercalated in kaolinitic underlying clay	as C; local bauxitization of underclay along joints, fractures and presumably plant roots; also pelitomorphous gibbsite after kaolinitic clay diapirs; narrow (10-100 cm) bauxite dikes vertically cut through underclay
COVER OR SOIL	tropical forest on thin soil layer insufficient to cover larger duricrust blocks	poor brush vegetation on very little soil	tropical forest on thin soil cover that fill many of the palaeocreeks	grass swamp and swamp forest on unconsolidated Miocene and younger sediments, northward increasing from 1-50 m; 2 layers of incipient ferralitic concentration in cover sediments
EROSION TOPOGRAPHY	hills are remnants of original larger plateau; surface erosion intensive resulting in fresh parent rock sticking through duricrust; locally very thick (25 m) accumulations on slopes	divide areas are remnants of extended planation surface dissected by dense dendritic network of creek valleys (5-20 m deep)	hills are remnants of extended sedimentary plain; surface contains dendritic network of shallow (1-3 m) creek valleys	as C; in addition lateral cutting action by Palaeo Para river with ox-bow and bauxite gravel in Para valley.
GRAPHICAL TYPICAL LOG Fe_2O_3 AND SiO_2 VERSUS DEPTH IN METRES				

(1979), from which table III is reproduced.

This cyclic variation in climate together with the sea-level changes indicated by the many regressions and transgressions resulted in the cyclic nature of the main geomorphological units of Suriname.

BAUXITIC AND OTHER DURICRUSTS

All five surfaces mentioned above show weathering phenomena, ranging in age from Jurassic or Cretaceous to Recent. The end products observed are mostly the result of more than one period of intensive tropical weathering, i.e. they are polyphase in origin. Detailed analysis of these polyphase weathering products, however, might provide information to identify the individual weathering phases.

This requires a closer look at a number of selected weathering profiles in their best preserved parts, the duricrusts of bauxitic or ferritic composition. The occurrences selected have been studied by different scientists with different purposes in mind. The present author has not seen all of them: some were studied by him in much detail, others only cursorily. The detailed data are given in the appendix, while a summary is given in table IV, which contains four data columns, each of them summarizing the features of one type of duricrust or bauxitic deposit:

(A) the high, flat, duricrust-capped mountains and hills in the central belt, represented by the Nassau and Bakhuis Mountains in the appendix.
(B) the 50-80 m high flat divide areas bordering the major northerly streaming rivers, represented by the Kwakoegron divide.
(C) the 0-80 m high flat-topped and bauxite-capped hills at the edge of the Coastal Plain, represented by the Moengo Hills.
(D) buried flat-topped and bauxite-capped hills underlaying the Coastal Plain, represented by the Onverdacht-Lelydorp deposits.

Near the bottom of each column is a very generalized histogram of the silica and iron-oxide contents of the duricrust profile, from the upper surface of the currently visible duricrust downward well into the underlying kaolinitic clay.

The data from table IV is summarized in figure 4, which shows graphically presented interpretations of the polyphase weathering history for the phenomena observed in the four types of profiles. The four stages portrayed are the quiet intervals between the five periods of active erosion, denudation and planation; it is during these quiet periods that *in situ* weathering could take place. Where this weathering process was of sufficient intensity and duration a hard duricrust could develop preventing the total removal of the weathered material during a later period of erosion, denudation and planation.

The legend in figure 4 explains the symbols used in the graphic interpretation, to which should be added that the thickness of the vertical arrows indicate the intensity of the weathering process in a certain period. In column A four phases of the weathering process are recognized, while in column B only two phases (the latest) occur. Evidently these later phases were not very intense, as only thin duricrusts developed on parent rock similar to those weathered in column A examples while post-weathering erosion was certainly less severe on these younger and lower divide areas compared with e.g. the Nassau Mountains.

The graphs in column C illustrate the weathering of Early Tertiary unconsolidated sediments during three weathering phases, while in column D the weathering is restricted to one phase only, because younger sediments buried the late Eocene-Oligocene weathering profile. Again, the later weathering phases cannot have been very intense as there is little difference in bauxite thickness or quality between the deposits summarized in columns C and D.

DISCUSSION

From the data given above, it appears that the Late Eocene-Oligocene period of weathering has been by far the most intense. This period alone provided the up to 10 m thick bauxite deposits in the Onverdacht-Lelydorp area.

The intensity of the saprolitic weathering process, however, is dependent on several factors:

(1) The climate (which must be sufficiently warm and humid) and the duration of each phase; these will have been similar for all the deposits reviewed.
(2) The porosity and permeability of the parent rock and the early weathering products; considerable differences exist between a schist, a granogabbro or an arenaceous unconsolidated sediment with respect to these parameters.
(3) The chemical and mineralogical composition of the parent rock; anorthosite with 28% Al_2O_3, andesite (greenschists!) and granogabbro with about 15% Al_2O_3, and arenaceous sediments depending on the feldspar content (with 18% Al_2O_3 in K-feldspar) give a wide range of chemical compositions.

Besides these main primary factors there are several others, partly of a derivative nature, e.g. the vegetation, the drainage as a function of the relief, the size of the divide area or plateau, the drainage pattern, etc.

In the case of polyphase weathering the products formed during an earlier phase will influence the weathering process during a later phase, while the erosional and denudational activities during intervening planation phases could either prepare the ground for an efficient weathering attack, or could completely remove the earlier weathering products, leaving a bare, all but unassailable rock mass behind.

The *Nassau Mountains* (DOEVE, 1955), with their extensive plateaus showing terraces of a few metres elevation differen-

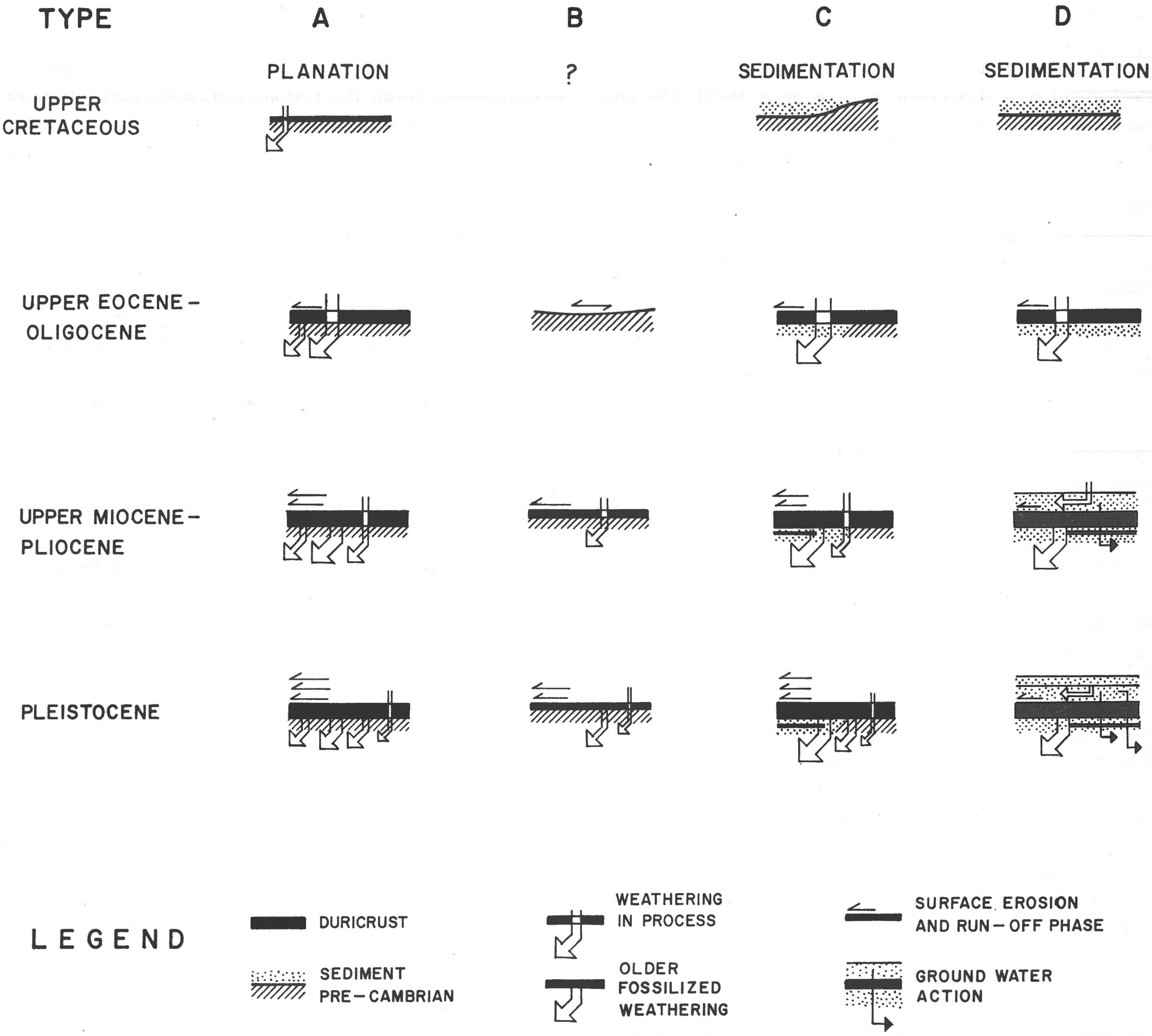


Fig. 4
Graphically presented interpretation of the weathering history of the four types of profile development in Suriname.

ce, could well be part of the original Gondwana surface. The limited thickness, in particular of the centre of the plateaus, indicates a slow progress of weathering. The increased thickness and locally occurring doubling of the bauxite horizon along the plateau edges seem to be the result of a later major weathering phase after the present size of the plateaus had been reached. Benches or terraces along the slopes of the mountains attest to the early origin of the plateaus themselves, as they must have formed as a result of later periods of erosion and denudation.

The *Bakhuis Mountains* (JANSSEN 1963, ALEVA 1970) are different; they are dissected along an intricate system of fractures resulting in relatively small individual plateaus. The terraces, benches and pediments along their slopes indicate an early development of the original plateaus, possibly also going back to the Gondwana surface. The Bakhuis plateaus are characterized by outcrops or suboutcrops of fresh parent rock of leucogabbro to anorthositic composition; hence erosion and denudation must have been intensive during the Late Tertiary planation periods.

On the slopes a thick mantle of (ferritic) bauxite may occur; pits and trenches in this mantle indicate a succession of large slabs (0.5-2 m thick) of bauxite material often with relict textures of the parent rock, intercalated with irregular zones (0.3-1 m thick) composed of bauxite in lens-shaped fragments and large amounts of botryoidal veins and sheets high in iron-oxide. The large-scale structure strikes parallel to the hill slope but the dip is somewhat less steep; the whole phenomenon resembles a pile of rock slides. Elsewhere, in a natural escarpment perpendicular to the hill slope, a heap of debris – or a boulder cone – is exposed, composed of bauxite throughout (see also KROOK & DE ROEVER, 1975). The most probable explanation is bauxitization after the parent-rock boulders were deposited, and that must have happened in a period that fresh parent rocks could still be produced higher up the slope. It is on slopes showing these phenomena that bauxite thicknesses up to 27 m occur. The progress of weathering must have been very high, probably because porosity and permeability were high and chemical and mineral compositions were favourable.

The *Kwakoegron surface* came into being in the Late Tertiary planation period I or II. The thin and far from massive duricrusts formed indicate a weak and slow action of the weathering process. The parent rock is comparable to that of the Nassau Mountains but drainage could have been poor for considerable time as a result of the low elevation. In addition time was short.

The *Moengo deposits* are formed on Palaeocene-Eocene sediments produced during the Early Tertiary planation period; hence their oldest age of formation is well established. At that time, however, probably no separate plateau hills existed: the weathering occurred over an extended area of unconsolidated sediments and the bauxite cap was essentially established before the incision of the deep valleys during the Late Tertiary I planation period, as can be established in the similar but buried hills at Onverdacht. Drainage, then, must have been relatively poor because of lack of relief and hence the other weathering factors must have been very good: permeability, porosity and composition. This is indirect proof that the original sediments must have been rather arenaceous (and not of a kaolinitic clay composition) with a considerable content in feldspar.

The buried *Onverdacht-Lelydorp deposits* (ALEVA, 1965) have a history of their own, although they started out in a similar way to those of Moengo. The sedimentary plain was dissected during the early stages of the Late Tertiary I planation period and the resulting plateau hills became buried during the late stages of the same period. Soil formation with incipient lateritization occurred during the late Miocene-Pliocene period, followed by renewed sedimentation and soil formation in Pleistocene time.

It is interesting to study the changes that occurred in the bauxitic duricrust as a result of burial under unconsolidated sediments in an environment of brackish formation- or groundwater and extensive local swamp development at several levels. The ferritic cap has largely been removed by solution and transportation of the iron oxide, resilicification of gibbsite into metahalloysite took place and there is a strong suspicion that gibbsite formation in the underlying kaolin clay must be related to this period as well, because these phenomena are not observed elsewhere in Suriname. Also the textures and structures observed in Onverdacht are different from elsewhere in Suriname.

CONCLUSIONS

The Late Eocene-Oligocene period of weathering was the most intensive during the Tertiary and Quaternary: all major duricrusts originated or were consolidated during this period.

The later weathering periods, in between periods during which planation surfaces were formed, probably did not add considerably to the thickness or composition of the already existing duricrusts. Only on the slopes of the Bakhuis Mountains plateau hills considerable bauxitization presumably occurred during these periods.

The primary saprolitic weathering of the planation surfaces developed during the Late Tertiary I and II phases and the Plio-Pleistocene phase, show successively weaker profile developments, with only some weakly plinthitic soil development on the last or subrecent surface.

ACKNOWLEDGEMENTS

The writer is indebted to numerous colleagues with whom he has had lively discussions on the genetic history of Suriname's bauxite deposits. The Management of Billiton International Metals B.V. is thanked for the opportunities given to visit and study numerous bauxite deposits in South America and for their support to publish this review.

APPENDIX

NASSAU MOUNTAINS (DOEVE, 1955)

Situation – Plateau-topped hills, 500-550 m high, with steep-sided flanks. The head-waters of the Paramakka creek separate four plataus, partly connected with narrow ridges and at other places by high passes. The individual plateaus have a somewhat rolling topography with a distinct northerly dip (1 to 250 or about one-fourth of a degree N to NE).

Parent rock – Described by DOEVE (1955) as Paramakka Series and Nassau Series of the Balling Formation, now contained in the Marowijne Group, composed of intermediate and basic volcanics, quartzites, phyllites, greenschists, etc., all greenschist-facies rocks.

Duricrust – Ferrite, bauxitic ferrite, ferritic bauxite and bauxite. Although highly variable from spot to spot, there is a general tendency for the middle part of the profile to contain the lowest SiO_2 and Fe_2O_3 values i.e. the bauxite proper (see Fig. 5 for analytical histograms).

Thickness: 2-4 m in the centre and locally increasing to 10-15 m along the edges of the plateaux.

Minerals: hematite, goethite, gibbsite and traces of boehmite; kaolinite in the lower part of the profile.

Textures: dense, 'oölitic', 'pisolithic', granular, pseudo-porphyric, pseudo-conglomeratic, breccia-like and porous

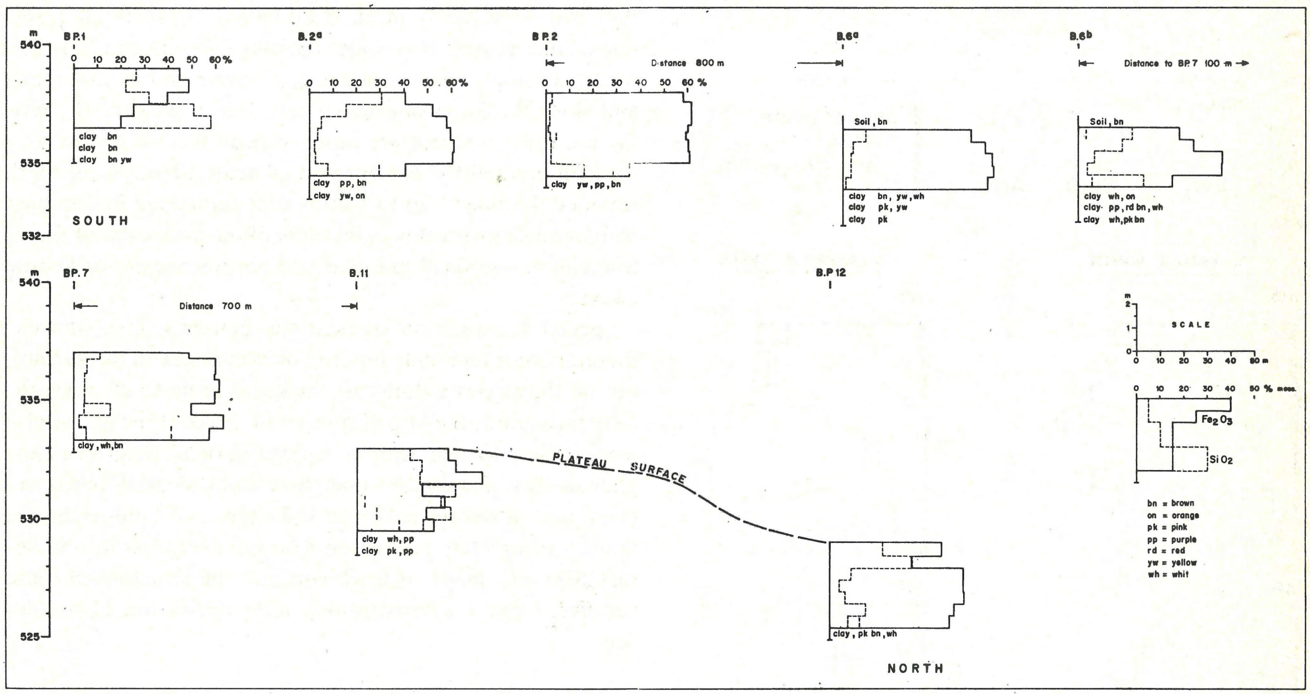


Fig. 5
Histograms of the SiO_2 and Fe_2O_3 contents of eight drill holes along a 2100 m long N-S section of the Nassau Mountains central plateau.

(DOEVE, 1955). Also irregularly shaped concretions (0.3-15 cm) in a clayey matrix.

Special features: the best-grade bauxite often occurs below swampy areas on the plateaus. Along the edges, where the duricrust is thickest, often two zones with better-grade bauxite occur. Little or no duricrust is reported from the steeper slopes below the plateaus.

Underlying clay – Kaolinitic clay; completely weathered parent rock for up to 20 m and probably more.

Soil or cover – A clayey layer, rock in humus materials, covers the plateaus in a layer 0-1 m thick; it supports a highly varying forest vegetation, mainly depending on drainage and duricrust development.

Geomorphology – On the plateaus several levels can be distinguished with up to 10 m difference in elevation; the steps between the levels are rather abrupt. Horizontal or slightly sloping benches occur in many places around the plateau-topped hills; they correspond locally with lower hill tops. These more or less horizontal features may be grouped according to their elevations: 460, 400, 300, 200 and 170 m in altitude; the lower the elevation, the farther away from the plateaus they occur.

Chemical section – In figure 5 some analytical histograms are presented.

BAKHUIS MOUNTAINS, plateaus 1, 8 and 10 (JANSSEN, 1963; ALEVA, 1970)

Situation – Flat-topped hills, 420-325 m high, steep-sided flanks; hill tops are either small plateaus with sharp escarpment-like edges or flatly domed with a rounded off transition to the hill sides. In the latter case fresh parent rock may be present at a depth of 0-3 m in the zone of strongest curvature.

Parent rock – Rock of the Falawatra Group with charnockitic and enderbitic gneisses, leucogabbros and anorthositic massive rocks.

Duricrust – Rocks: ferrite, ferritic bauxite and bauxite are present, often alternating in a horizontal direction at short (m to tens of m) distance.

Thickness: average 3-5 m, with maximum figures (up to 27 m) mostly on the lower parts of some of the slopes, and minimum figures, including complete absence, on the flat hill tops.

Minerals: hematite and aluminous goethite in varying proportions without clear vertical arrangement; gibbsite and traces of boehmite; kaolinite is often admixed in the lower part of the profile while in other places the transition to the underlying clay is knife sharp (from 4% to 28% total SiO_2).

Textures: in the upper, mostly rather hard part of the profile, relict textures of the parent rock are frequently seen;

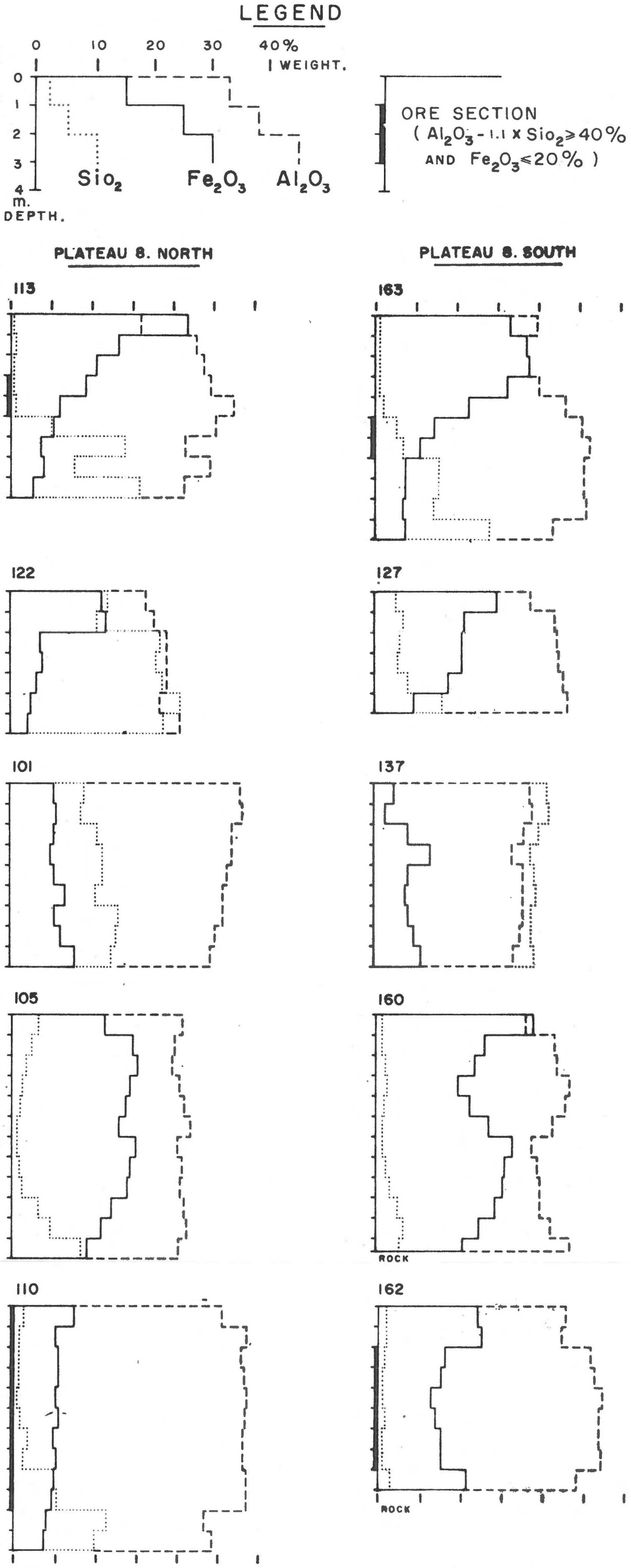


Fig. 6
Histograms illustrating the SiO_2, Fe_2O_3 and Al_2O_3 distribution in some drill holes from the plateaus 8 North and 8 South, Bakhuis Mountains.

they are often partly masked by local iron oxide encrustations, concretions, botryoidal banding, pseudo-pisoliths etc. which develop preferentially in cracks, semi-horizontal joints and along the edges of escarpments. Lower down in the profile the relict textures are more difficult to discern but they are still frequently present (on plateau 10 often as hard, rounded 'boulders' up to 1 m in size, embedded in the main bauxite mass) with this main mass often composed of fine – to medium – grained granular and porous bauxite or ferritic bauxite.

Special features: on or near the plateaus fresh, unweathered parent rock may outcrop or occur near to the surface, but on the slopes a duricrust thickness of up to 27 m (vertically measured) may be encountered. From trenches on plateaus 8 and 10 and from a natural vertical outcrop below plateau 10 it is apparent that these thick slope deposits are composed of debris, rock and soil slides and boulder heaps, now all completely bauxitized with relatively few iron minerals. Size and shape of fragments and the structure of these deposits suggest a bauxitization after deposition of the debris.

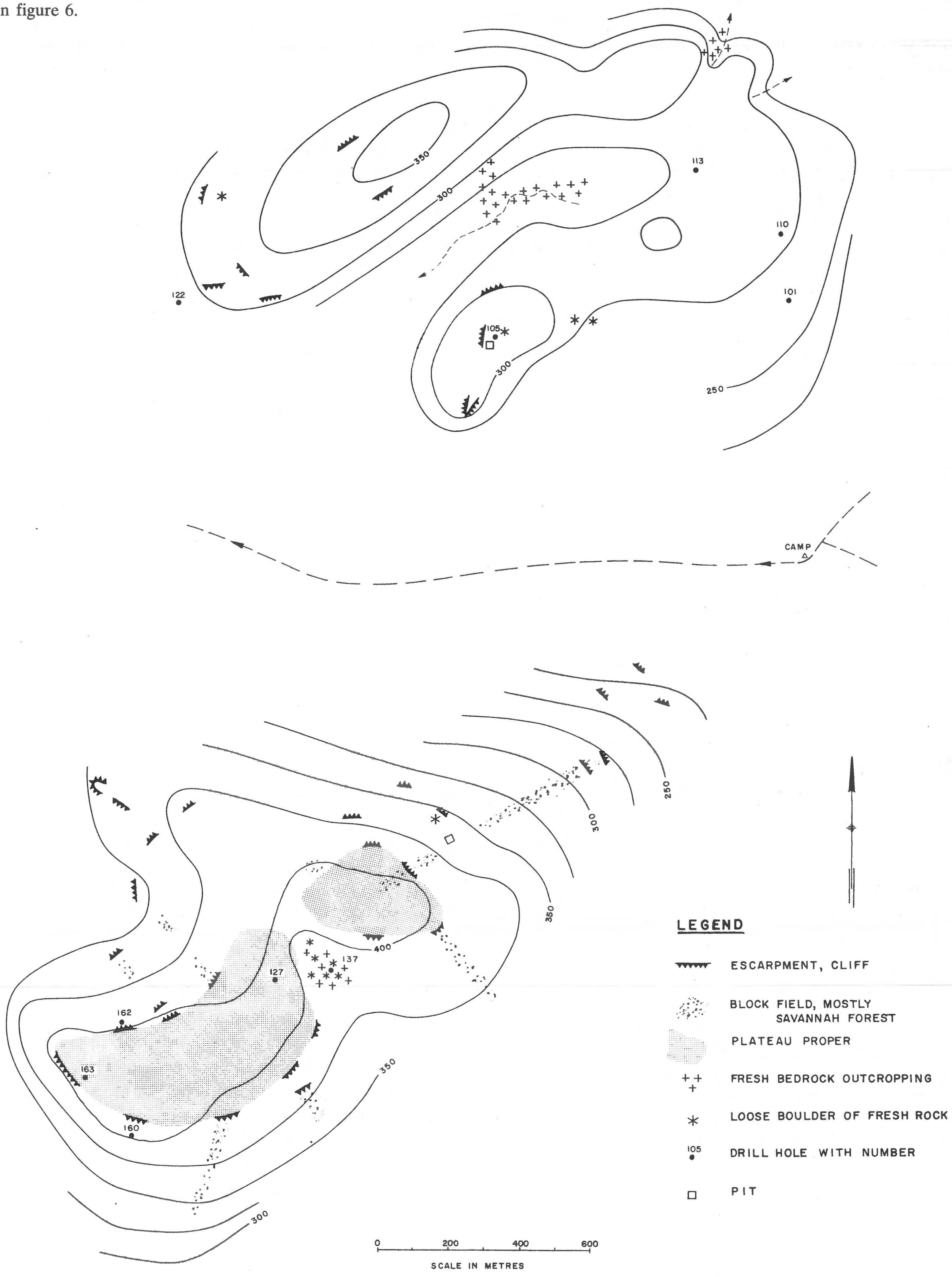
Underlying clay – Kaolinitic clay, often with low porosity resulting in a wet layer just above the clay layer (often resulting in loss of samples during drilling). In the top part small pure gibbsite nodules may be present. No visible structure or texture.

Soil or cover – The slopes are covered with tall tropical forest which produces a 0.5-1 m layer of humus-rich soil and duricrust debris. On the plateaus this soil layer is insufficient to cover the larger duricrust blocks; the forest is here less luxuriant and often grades into a thin savanna forest with very hard and tough lumber. In many places a dm thick layer of 'iron beans' is present; they are 5-15 mm in diameter and of the coated-grain type.

Geomorphology – The hills seem to be part of a larger northward dipping planation surface, which is 150-200 m above the surrounding closely dissected and rolling landscape. On a topographic or aerial photographic map it is apparent that the individual hills are separated from each other along a joint system that appears over a larger area which, together with the specific high-grade metamorphic rocks of the Falawatra Formation, defines the NNE trending Bakhuis horst. The steep-sided valleys between the plateaus are marked by several levels or terraces with very iron-rich duricrust formation with predominantly concretionary and botryoidal textures. KROOK & DE ROEVER (1975) recognize two bauxitized pediments on the slopes of the area 10 hills.

Chemical section – Some analytical histograms are given in figure 6: the location of the selected holes are marked on the map of figure 7. In general, the economic potential of the duricrust is determined by the absence, or strong decrease

Fig. 7
Contour map of the plateaus 8 North and 8 South. Bakhuis Mountains with some geological data and the location of drill holes used in figure 6.



with depth, of iron, as in the top part of the duricrust profile silica is mostly low (less than 3%).

MOENGO HILLS (Ricanau, Adjoemakondre, Begi Gado, Jones, etc.)

Situation – Flat-topped to plateau-shaped hills with an elevation of 40 m in the north to 100 m in the south. These irregularly shaped hills occur as divide areas in between the consequent, dendritic creek pattern on the southern border zone of the Coastal Plain. There are 10 larger and several smaller hills in an area measuring 20 km (W-E) by 10 km (N-S).

Parent rock – Unconsolidated sediments of the Onverdacht Formation of Palaeocene to Eocene age, composed of alternating quartz-sand layers and kaolinitic clays. The sand content increases downwards, becomes coarser and finally changes into a well-rounded quartz-pebble layer of up to 2 m thickness which lies unconformably on Precambrian granites and gneisses. Several of the hills contain a core of weathered Precambrian schists belonging to the Marowijne Group, but the duricrusts are separated from the Precambrian by several metres of Tertiary Onverdacht Series.

Duricrust – Bauxite and ferritic bauxite with local ferritic development.

Thickness: average 5 m with variations from 1 to 8 m.

Minerals: gibbsite and hematite with only traces of boehmite and locally goethite. In the lower part of the profile some admixture of kaolinite may occur.

Textures: the often iron-rich top part of the profile contains breccia-like textures, the less iron containing parts are often fine- to medium-grained granular with lower down in the profile an earthy texture with irregular concretions. There is no clear layering with respect to texture.

Special features: layers with an abundance of mostly horizontally diverging tubular features can be found in the bottom part of the bauxite profile and at lower levels in the underlying clay (see below). Also in these lower parts, in the transition zone between bauxite and clay, tubular and spindle-shaped concretions occur, composed of dense, microcrystalline, almost white gibbsite. Both these features have been described by VALETON (1971) as fossil roots. Other tubular features mostly found in the lower parts of the bauxite (and not in the underlying clay) are interpreted by Valeton as replicas of animal burrows, often with a clearly visible filling-up texture.

Underlying clay – Kaolinitic clay alternating with coarse sandy layers 5-20 cm thick. The layers nearest to the overlying bauxite are largely composed of white gibbsite, with solution remnants of quartz in larger, angular voids, indicating a replacement of the sandy layer by gibbsite. Lower down the content of original quartz grains increases progressively (VALETON, 1973).

Soil or cover – Tropical forest covers the surface of the plateaus; the trees root in a thin layer of sandy-clayey material rich in humus. Before mining can take place all cover must be removed and then the original bauxite surface becomes visible over larger areas. This surface is marked by a dense creek or gully system with a gully width of 5-10 m and a depth of 1-3 m below the surrounding flat plateau. Both on the flat plateau areas as well as on the bottom of the gullies there is a layer, 10-40 cm thick, of small (0.5-2 cm) rounded concretions of a high iron and silica composition ('iron beans').

Geomorphology – The plateau-topped hills are clearly the erosion remnants of one or several much larger plateaus, dissected by a drainage pattern similar to the present pattern, but evidently with a much higher erosive power (lower erosion base): the present valley floors are – at least in several places – composed of chemically completely weathered rocks of the Precambrian basement with only a thin veneer of (sub)recent sediments or soil, as could be seen in the ditches along the rail spur to the Begi Gado plateau during its construction.

Chemical section – No published data available.

ONVERDACHT-LELYDORP BURIED HILLS (ALEVA, 1965)

Situation – The Older Coastal Plain is composed of sand ridges and islands of the Coropina Formation with in between swamps and filled-in oxbows (Demerara Formation) of the Para and Suriname rivers. The elevation is +3 m for the sand ridges and +1 m for the swamps; tide movement is about 1-2 m in this area. Farther west from the rivers the Lelydorp sands (Upper Coropina) form the highest features in the landscape with about +6 m elevation.

Buried beneath these unconsolidated sediments, and in no way discernable from the surface, are at least five plateau remnants topped by bauxite (see Fig. 8).

Parent rock – Unconsolidated sediments of the Onverdacht Formation of Palaeocene to Eocene age (VAN DER HAMMEN ET AL., 1961), consisting of a lower coarse-grained kaolinitic sand layer on the weathered Precambrian bedrock and an upper tough, white kaolin layer. In places a sandy layer of similar description is intercalated in the kaolin layer.

Duricrust – Bauxite, often of very high gibbsite content, ferritic bauxite and locally some ferrite.

Thickness: average 6-7 m with variation from 2 to 13 m; the bauxite dips at 0.3 degrees north.

Minerals: gibbsite, hematite with, in the lower part of the profile, an admixture of some kaolinite; boehmite generally less then 0.1%, no goethite detected.

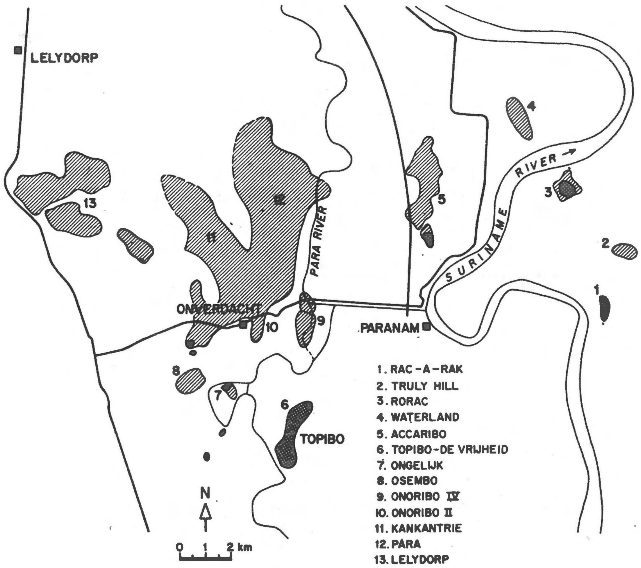


Fig. 8
Map of the Onverdacht-Lelydorp area showing the approximate outline of the known bauxite deposits. Only the cross-hatched deposits outcrop; all the others (parallel hatched) are buried.

Textures: top part of profile with breccia-like textures, locally some concretionary and even botryoidal textures in the ferritic parts. Main, iron-poor, part of profile exhibits concretionary, cellular[3], and tubular textures, often with a clayey (but pure gibbsite in composition) matrix or filling of cells. Near the bottom of the profile box-work textures[3] (with either plastic gibbsite or kaolin or empty space in the chambers) often occur which either grade into the underlying clay or are sharply bounded by a flat slabby bed of medium-grained granular bauxite with kaolinitic lenticles parallel the bedding plane (which are often covered with heavy minerals i.e. rutile).

Special features: the top 2-3 m of the bauxite profile is largely altered through removal of most of the iron without changing the texture materially. Some inverted pyramidal remnants of the original iron-rich cap are still preserved, and in both the low iron and high iron parts neoformation of metahalloysite occurs in stringers and branching veins down to a depth of 2-3 m.

In the lower part of the profile many relict sedimentary features can be observed, indicating that the layers or beds with higher porosity of the parent material were preferentially transformed into bauxite. In the pure kaolinitic clays the deposition of gibbsite is restricted to joint planes, tension cracks, etc.

Underlying clay – Tough, white kaolinitic clay with thin horizontal streaks of black heavy minerals and locally bedding planes covered with colourless mica flakes. The contact with the overlying bauxite can be sharp or gradational over several dm. Below and more or less parallel with the main bauxite bed, at a vertical distance of 0.5-3 m, a 0.5-5 dm thick second bauxite bed may occur, brick-red in colour, fine- to medium-grained and with a granular texture. These lower beds are always clearly bedded with sometimes small kaolinitic clay lenticles interbedded; they may also contain layers rich in heavy minerals (rutile) to the extent that the rock becomes friable due to lack of cementing gibbsite. Other sedimentary structures observed are described by ALEVA (1965). Vertical 'dikes' of mostly very porous, cellular to box-work bauxite occur, which cut through the underlying clay in a NNW direction; they are 0.1-1.0 m thick and some extend downward for at least 6-8 m. The bottoms of these dikes have never been uncovered. Pollen have been found in a few dark-gray kaolin seams, rich in organic material; VAN DER HAMMEN ET AL. (1961) have determined the age of the pollen association, found at 21 and 24 m below the bauxite bed, to be of Palaeocene age.

Soil or cover – The cover of unconsolidated sediments of Miocene and younger age, increases from a few metres in the south to over 40 m at 5-6 km farther north. MONTAGNE (1964) described these cover sediments and the stratigraphy in detail. He mentions two levels of incipient lateritization.

Removal of all overburden before mining exposes the bauxite surface over larger areas, which appears to contain a fairly intricate dendritic drainage pattern of valleys, about 2-3 m deep and 5-20 m wide. Along the eastern edge of the Para lobe of the Onverdacht bauxite deposit it could be deduced with certainty that the bauxite-capped plateau has been cut off by an oxbow of the palaeo-Para river, leaving a small bauxite Inselberg standing separated from the main mass.

Geomorphology – From drilling data it can be deduced that the bauxite-capped Onverdacht palaeo-plateau, composed of Palaeocene unconsolidated sediments, once stood as a solitary hill in a plain underlain by Precambrian basement rocks, washed bare of all younger sediments by the forerunners of the Suriname and Para rivers and their tributaries.

Starting in the Miocene renewed subsidence and sedimentation filled up the wide plain between the bauxite-capped palaeo-plateau hills and later covered most of these completely (the Acaribo hill just outcrops with its southern edge). The drainage pattern on the Onverdacht palaeo-plateau must have originated before the dissection of the Palaeocene sedimentary deposits into separate hills. The cross section of the bauxite cap, with a thick central part and thinning towards the edges, would indicate the formation of the duricrust on a lens-shaped lithological unit, which armoured the underlying unconsolidated sediments against fluviatile erosion.

Chemical section – See ALEVA (1965).

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[3] Here 'cellular' indicates rounded, bulbous or irregular thin-walled chambers, while in the box-work texture the chambers are bounded by intersecting flat and thin plates of gibbsitic composition. This is an elaboration on the terminology used in Aleva (1965).

KWAKOEGRON planation surface and hills

Situation – Starting south of the savanna belt the landscape contains three distinct elements:

(1) an extensive southward rising planation surface at 50 to 80 m elevation, dissected by an intricate dendritic creek system;

(2) creek valleys mostly with a distinct flat valley floor at about 20 m elevation;

(3) rows or groups of monadnock-like hills with an elevation of 100 to 250 m.

Parent rock – Low-grade metamorphic schists of the Marowijne Group.

Duricrust –(Bauxitic) ferrites and some laterites.

Thickness: varying from place to place between 0.5 and 5 m: on the planation plane mostly thin, on the higher hills mostly thicker.

Minerals: not studied in detail.

Textures: top part of profile often with small (5-20 mm) rounded concretions, nodules and 'beans' of high Fe_2O_3 content. Lower part mostly more cellular, irregular, concretionary and mixed with kaolinitic clays; size of features in the 20-40 mm range.

Underlying clay – Kaolinitic clay, mostly within a few metres below the duricrust profile with visible colour banding and relict textures of the parent rock.

Soil or cover – The mostly poor forest cover roots in a thin humus-containing soil cover which, however, locally can be almost completely removed (truncated profile).

Geomorphology – The area gives the impression of being dominated by the lowest of the cyclic planation surfaces observed in Suriname, the Tertiary II surface of Pliocene age. The monadnock-like hills seem to be the last remnants of the Tertiary I surface.

Chemistry – Little data are available. The ranges and averages of seven drill samples from an extended divide area SE of Kwakoegron are as follows:

SiO_2	7.2 – 14.9%	$\bar{X}$ = 11.0%
Fe_2O_3	55.1 – 70.7%	$\bar{X}$ = 62.0%
TiO_2	0.6 – 1.7%	$\bar{X}$ = 1.0%

Addendum – In a similar geomorphological position (presumably the Tertiary II surface) a bauxitic crust on doleritic parent rock has recently been observed by the author near the Upper Tibiti river rapids. The analysis of one sample gave:

Al_2O_3 (rest)	43.0%
Loss on ignition	24.5%
Fe_2O_3	21.9%
SiO_2	8.7%
TiO_2	1.9%

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